

WEATHERPROOF AND WATERTIGHT DIGITAL ELECTRONIC CAMERA, INCLUDING
A SOLID OR FLUID-FILLED DIGITAL CAMERA OPERATING AT GREAT DEPTHS

BACKGROUND OF THE INVENTION

1. Field of the Invention

5 The present invention generally concerns digital electronic cameras, and waterproof housings for cameras including digital electronic cameras.

10 The present invention particularly concerns the communication of (i) information, (ii) control and (iii) power across a watertight barrier, particularly such as may serve to protect an electronic instrument, most commonly a digital electronic camera, including when the instrument is immersed in water.

2. Description of the Prior Art

15 2.1 Relevant Previous Patents

20 A significant body of prior art concerning waterproof housings for conventional film cameras is substantially irrelevant to the present invention for several reasons. First, the housing or case for a conventional, non-electronic, camera must open for retrieval and replacement of the film -- as will prove to be unnecessary with a digital electronic camera. Second, since the camera's case or housing will open, and required replacement of batteries is readily accomplished by physical substitution, no battery recharging need transpire through the case or housing.

25 The case and its waterproof seals can be, and often are, quite sophisticated in supporting the transmission of mechanical forces and adjustments as may attend, inter alia, adjustment of the camera's focus and/or the actuation of its shutter. However, and although a digital electronic camera may have a focus adjustment and will have a shutter, these mechanisms can be electrically, as opposed to mechanically, actuated.

30 Accordingly, the present invention will prove more analogous to certain prior art underwater electronic devices -- including

electronic imaging devices such as, inter alia, a video tape recorder -- than to underwater film cameras. (Of course, even with a video tape recorder, a watertight enclosure will open for access to the videotape.)

5 In this regard, United States Patent number 3,952,190 to Perkins for an UNDERWATER STROBE FLASH UNIT concerns a method of waterproofing a strobe flash unit for use in underwater photography. A mold is formed and a strobe flash unit is mounted within the mold. Epoxy resin is poured into the mold to surround
10 the strobe flash unit with the resin. The resin is then cured until it hardens, at which time the mold is removed from the epoxy resin and strobe flash unit. The resultant product is a strobe flash unit encapsulated in a transparent waterproof casing. Such encapsulation will be seen to be suitably employed in the present
15 invention.

As regards the communication of power to a hand held
underwater electronic imaging device, United States Patent number
4,009,419 to Ligman for a SAFETY CIRCUIT FOR VIDEO DIVER concerns
an underwater diver who is provided with a video camera, light, and
20 communications all of which is supplied with electrical current
from the surface by a shipboard electrical circuit. The diver is
protected from accidental excessive voltages and current by
magnetically isolating the diver's current from the shipboard
current and by employing optical feedback to control the voltages
25 for the diver. Additionally, a standby battery is employed to
energize this equipment when the shipboard power fails. The entire
shipboard power supply is contained in a waterproof box upon which
is also mounted a video monitor and a video recorder, both secured
in watertight fashion to the box. The present invention will be
30 seen to involve the transmission of power into a waterproof
enclosure, but not while the enclosure is immersed, and normally
not while an electronic digital camera within the enclosure is in
use.

The present invention will be seen to involve optical data.

transmission. United States Patent number 5,847,753 to Gabello, et al., for a CAMERA SYSTEM FOR SCANNING A MOVING SURFACE concerns a camera system utilizing a line scan (linear array) camera designed to scan a moving surface and subsequently to generate and to transmit a high quality digitized video signal over a long a distance by an optical fiber. The primary function of the system is: to scan a moving surface using a 2048 or a 1024 linear array; to condition and digitize the array analog video signal; and subsequently to transmit to a computer processing unit, without a noticeable loss in fidelity, the digitized video data over a long distance by means of an optical fiber connected to the camera and the computer processing unit. The system also functions to transmit both video signals and non-video information signals over a fiber optic link from the camera to the computer processing unit.

2.2 An Exemplary Modification of an Existing Digital Camera

The present invention will be seen to employ but very, very slight -- substantially inconsequential -- physical and electrical modifications to an existing digital electronic camera. No modifications at all are required by the present invention in the personal computer, nor in the operating software, that are commonly used to recover digital images from the digital electronic camera. However, all these things are readily susceptible of modification, if required.

It is thus useful to consider the susceptibility of a digital electronic camera to electrical and/or physical modification. An example of modifications -- much more extensive than are required by the present invention -- to an existing digital camera to support of its use in a non-standard, space borne, environment is shown in a Stanford University student project reported on the World Wide Web at <http://maverick.stanford.edu/>.

2.2.1 An Exemplary Existing Digital Electronic Camera

The Logitech Fotoman Plus digital electronic camera is a 8-bit

grayscale digital camera, capable of storing 32 JPEG compressed pictures in memory. Its specifications, according to Logitech, are as follows:

The camera dimensions are 16.8 centimeters (6.7 inches) by 8.1 cm (3.2 in) by 3 cm (1.2 in). The camera weight is 284 grams (10 ounces).

Camera image quality is 256 gray levels over 496 x 360 pixels, for an equivalent resolution of 120 dots per inch (120 dpi) over a photo approximately 4 in (12.7 cm) wide x 3 in (8.9 cm) high.

The lens is fixed focus with a 8.5 millimeters (mm) focal length, f/4.5. The 35 mm camera equivalent focal length is 64 mm. Shooting range is 3 feet (1 meter) to infinity.

The camera's equivalent film sensitivity is approximately ASA 200 without the neutral density filter; and approximately ASA 25 with the filter.

The camera's electronic shutter speed is 40 milliseconds (~1/30) with the flash, and 0.5 to 50 msec (1/2000 to 1/20) without the flash.

The flash guide number equivalent is 27 at ASA 200. The flash shooting range 3 ft (1 m) to 8 ft (2.5 m). The life of the flash is 10,000 flashes.

The image capacity of camera is 32 pictures in an image storage medium: namely, solid state (dram) memory with battery backup.

The image sensor type is a CCD (charge-coupled device). The raw image size is 179 kb (8 bits per pixel). Compressed image size varies with the image. Average compressed image size is 23 kb with 8:1 compression using the JPEG image compression method.

The adapter rings have a small end of 27 mm threaded outer diameter, and a large end of 37 mm threaded inner diameter.

The camera cable length is 6 ft. (2 m) of cable suitable for the camera's RS423 serial interface (which is simply +/- 5v version of the more famous RS232 serial interface, which will be seen to be the type used in the preferred embodiment of the present

invention).

The baud rate of the interface is 9.6 K baud receive, and 9.6K, 19.2K, 38.4K, 57.6K, of 115k baud transmit.

The main power source of the camera is two rechargeable nickel-cadmium batteries, AA size, 600 ma, 1.2 V. The time needed to charge these Ni-Cad batteries is 6 hours minimum. In estimating loss of charge in the Ni-Cad batteries assume that, at room temperature, the batteries lose about 20% of a full charge every time the camera takes one full load of photos (32 photos). The batteries lose about 15% of a full charge every time the camera goes 24 hours without recharging.

The battery charger has an output 12 vdc +4 v, -2 v, 500 mah minimum. The polarity-positive pole is at center.

A memory power source is based on a 3 v lithium cell.

Camera operating temperature and humidity is 0 to 40 °C at 95% humidity or less. Camera storage temperature and humidity is -40 to 50 °C at 95% humidity or less.

An existing Logitech Fotoman Plus digital camera (the "Fotoman camera") is modified by, among other things, placing it in a protective box. The capabilities of this digital camera include JPEG image compression, storage in DRAM of up to 32 x 496 x 360 images with 8-bit grayscale in compressed form. The compression results in a JPEG image size of about 23 Kb.

A serial link to the CPU, RS-232, is used to load into the Fotoman camera memory its operating software, to give it instructions, and to transfer back the camera status and full images.

The digital camera can be powered on/off, from the +5 V bus of the spacecraft. A voltage regulator and a bypass capacitor are used to replace the Ni-Cad batteries normally used to power the Fotoman Plus (see schematic) A lithium battery, used by the Fotoman to maintain the operating software in memory, is left in the camera.

2.2.2 Exemplary Previous Electrical Modifications to an Existing Digital Electronic Camera

In accordance with the present invention, connection will be made to the circuitry of a digital electronic camera. That a connection to -- and more, rising to the level of actual modification of -- the circuitry of an existing digital electronic camera might be made is known.

For example, the aforementioned Fotoman Plus digital electronic camera was subjected to electronic modifications. The Fotoman Plus camera was already designed with appropriate digital communications interfaces without the need for any custom adapter. However, an external switch controlled by the on/off command from the CPU and voltage regulation had to be added. It was so added by wiring an existing RS423 serial interface from a bottom 6 electrodes already present in the camera. (With the lens on top, the six electrodes from left to right are: 1. Connection directly to the battery through a fuse, located in the camera, which is used to monitor battery level in manufacturing. A battery eliminator could be connected, but the fuse would have to be bypassed; 2. RS423 out; 3. Charge in (+12 V); 4. RS423 in; 5. Ground, used for both power and RS423; and 6. Unused.)

Next, a power regulation and switching circuit were designed to turn on the Fotoman camera if a "on" signal was received from the CPU through the bus or the space satellite in which the modified camera was to be flown, and contained

Finally, the flash had to be selectively electronically disabled by removing certain components off the PCB. (The components were C32, Q18, Q24, Q27, R94, and R93, as indicated on the printed circuit board of the camera.)

2.2.3 Exemplary Modifications to the Software-Based Interface and Control of an Existing Digital Electronic Camera

It will be seen to be one of the strengths of the present invention that no modification is needed to the firmware within the

camera, nor the software within a connecting computer. It will be understood, however, that such minor modifications as might be required are well within the skills of a practitioner of the digital computer programming arts.

5 For example, the Fotoman Plus camera has a command set the detail nature of which is not of particular concern in the present application.

Using this instruction set software for control of the camera was modified in accordance with the space mission of the camera.

10 The Fotoman Plus camera software architecture is based on a boot code stored in the Fotoman Plus camera ROM. This main code stored in the Fotoman Plus camera RAM is known as FOTOWARE. This code operates the Fotoman Plus camera, performs the data compression, and manages the communications with an external computer through a serial link.

15 The Fotoman Plus camera software architecture is also based on an exploitation code, known as FOTOTOUCH, based on an external computer. This code contains a dialogue/acquisition segment, an executable named FOTOMAN.EXE, and an image processing segment.

20 Finally, the Fotoman Plus camera software architecture is also based a native mode communication program TERM permitting ASCII commands to be used in commanding the Fotoman Plus camera to be entered via a keyboard.

25 The camera modification plan called for a special version of the FOTOWARE that permitted programmed (i) disabling of the flash, (ii) manual setting of the exposure time, and (iii) control of the battery counter. The battery counter is a model of the battery maintained by the FOTOWARE, which does not measure any physical quantity from the batteries. However, the battery counter must be 30 above a certain level, before the Fotoman can take a picture.

However, if the camera batteries are removed and replaced, the on-board software assumes that the replacement batteries are uncharged. As the power circuitry for the digital camera replaces the batteries, on power up, the counter will read zero and the

camera will not be able to take a picture. By controlling the counter, the programmer(s) can change the erroneous indication of insufficient power, and can take a picture immediately. Flash control is recommended, as the flash will be physically disabled.

5 FOTOTOUCH or any other standard image manipulation package can be used in the ground station to view and process the images, which are downloaded in standard JPEG format.

2.2.4 Exemplary Use of a Modified Existing Digital Electronic Camera

10 The present invention deals with a digital electronic camera modified for underwater use. It is known to attempt to modify a digital electronic camera for a specific applications environment, to wit: the space borne application of the Fotoman Plus camera.

15 In that application full new software supports camera dialogue/acquisition with the spacecraft CPU, and interfaces the camera into the main control module of the spacecraft. This software performs the following tasks: 1. turning on and off the Fotoman Plus; 2. uploading FOTOWARE from the PROM into the Fotoman Plus RAM at a given time; 3. sending orders to take pictures to the Fotoman; 4. Request and receiving status, contact, and image inventory information; and 5. retrieving pictures from the Fotoman, to be stored in the CPU, which will be sent at a later time to the ground station.

20 These tasks can be performed using the 16 commands set of provided in the Native Mode Toolkit.

Typical tasks for the modified FotoMan executable under software control are to 1. take a picture at a given time (using the on-board clock); and 2. download a picture #n stored in CPU memory.

30 For further explanation see the Fotoman Plus camera User's Guide (a basic user's guide) and the Fotoman Plus Camera Native Mode Toolkit (logical interface specifications) supplied by Logitech Inc., Fremont CA 94555. See also JPEG documentation and

5 SUMMARY OF THE INVENTION

The present invention contemplates a weathertight and watertight digital electronic device, particularly a digital camera, that is designed to operate both on land and underwater to great depths. The camera is preferably hermetically sealed, and is thus impervious to contamination both from the atmosphere -- such as may arise from wind-blown sand and smoke -- and from water and like fluids, including during full immersion including at great depths and pressures. The hermetic sealing is realized by an encapsulating housing, or case. This housing is totally without any passage of (i) electrical wires or cables conducting electrical current, or of (ii) mechanical plungers or actuators imparting mechanical force(s), through its wall(s). Thus when the housing is described as "hermetically sealed" in this specification then this term means more than "airtight", but, as will be seen, less than "immune to external influence" -- as are both dictionary definitions of the word "hermetic". The concept of "hermetic sealing" of a digital electronic device, or camera, in accordance with the present invention is this: there are no seals, nor any points of substantially different vulnerability to breach, within the entire housing. Indeed, the housing may be molded as a monolithic block. Its surface may be fashioned -- at least so far as regards possibilities and potential for ingress or egress to the digital camera or other electronic device contained inside -- as a continuum, meaning by dictionary definition something of which no

distinction of content may be affirmed except by reference to something else. In simplest terms, once sealed shut the housing is solid, and like as a monolith without any physical passages whatsoever within its surface.

5 Nonetheless that the watertight digital electronic camera of the present invention is hermetically sealed -- or possibly because it is so hermetically sealed -- its housing, and all necessary electrical and digital electrical communication with the camera, are economical to manufacture. This economy results primarily because, as explained above, there are absolutely no physical passages through the housing of the camera, nor are any expensive waterproof fittings employed. Indeed, in one of its embodiments the housing of the camera is formed by completely encapsulating the camera, and some modest auxiliary electronics, within a solid block of, preferably, plastic during a potting process.

10 The hermetically sealed watertight digital electronic camera also constructed is characterized by having all necessary (i) signal, (ii) control and (iii) power communication with the camera transpire by and through radiation links that pass through the housing of the camera.

15 Regarding (i) signal communication, the communication of image data from the camera to the exterior of its transparent case is preferably via a radio or, more preferably, an optical link, most preferably an infrared optical link.

20 Regarding (ii) control communication, the watertight digital electronic camera so constructed is further characterized in that communication of an actuation signal to the shutter of the camera preferably transpires via a magnetic link. In the preferred embodiment a trigger circuit based on a Hall-effect sensor or a reed switch, and located interior to the sealed case, produces an electrical signal suitable to actuate the camera's existing shutter circuit whenever a small permanent magnet exterior to the case is brought into proximity, normally by manual movement in a simple sliding mechanism in a manner suggestive of a standard shutter

release.

Regarding (iii) power communication, the watertight digital electronic camera so constructed is still further characterized in that the camera has, quite conventionally, a rechargeable source of power, normally a battery. This power source is, however, quite un conventionally recharged via an inductive coupling. In the preferred embodiment of the camera an oscillating, alternating current (a.c.), electromagnetic field external to the camera housing is inductively coupled into (i) an inductive coil internal to the housing. Also internal to the housing, (ii) a bridge rectifier rectifies the alternating current induced in the inductive coil to produce a direct current, and (iii) a regulating and charging circuit conditions this direct current into power to charge the rechargeable power source.

As a still further major aspect of the present invention, the housing -- which is normally formed quite snug to the camera and its auxiliary electronic circuits -- may be filled with an optically-transparent electrically-dielectric liquid. The housing may even be formed by potting: solidifying a liquid polymer that extends into all regions and volumes of the housing -- including inside the camera proper -- into a solid block of optically-transparent electrically-dielectric plastic. This construction, which leaves the enclosed volume of the housing substantially entirely devoid of gas, permits that the waterproof camera may be used at great depths of, at least, a mile; and may be non-destructively subjected to correspondingly great hydrostatic pressures. Any necessary preset to the lens system of the camera to account for the differing indexes of refraction of air and of the potting plastic is contemplated.

1. An Underwater Digital Electronic Camera System

Therefore, in one of its aspects the present invention will be recognized to be embodied in a waterproof digital electronic camera system suitable for use underwater. The system includes (i) a

digital electronic camera, and (ii) a converter, in (iii) an enclosure.

The (i) digital electronic camera has a digital electrical signal interface for downloading image information from the camera.

5 The (ii) converter converts signals upon the digital electrical signal interface to optical or to radio frequency signals.

10 The (iii) enclosure hermetically seals water and air tight both (i) the digital electronic camera and (ii) the converter. The enclosure is transparent in at least an area of lens of the digital electronic camera so that pictures may be taken through the enclosure. The enclosure is additionally transparent to radiation so that either an optical, or a radio frequency, signal output of the converter -- which signal contains image information -- is communicable exterior to the camera.

15 The (i) digital electronic camera typically has a serial digital electrical signal interface, and most commonly an RS-232 interface, thus making that (ii) the converter is converting signals upon this serial digital electrical signals interface to serial optical, or radio frequency, signals. The preferred converter in particular includes (a) an RS-232 to TTL signal converter converting RS-232 serial digital electrical signals to Transistor-Transistor Logic (TTL) serial digital electrical signals, and (b) an encoder-decoder converting the TTL electrical signals to electrical signals that are suitably encoded so as to be converted to optical or radio frequency signals for further transmission. The converter further has (c) an electrical-to-optical, or an electrical-to-radio, signal converter for converting the encoded electrical signals to optical or radio signals, and for transmitting the optical or radio signals through the at least one radiation-transparent area of the enclosure.

25 Conversion need not be realized in a converter having these exact functional or physical sections (a) - (c). For example, in one embodiment of the invention an RS-232(C) electrical signal to

and from the camera goes directly to a (spread-spectrum) radio frequency transceiver module for bi-directional communication outside the camera. Moreover, in many embodiments of the camera system some or all of these three sections (a) - (c) of the converter may be hard to locate, and distinctly identify. For example, all three sections (a) - (c) may be combined in an optical, or in a radio, transceiver. It will be recognized by a practitioner of the electromagnetic communication arts that there are diverse ways of communicating electrical signals upon an electronic device, particularly a digital electronic camera, bi-directionally through a radiation-transparent window located in a case encapsulating the device (the camera).

Further in the preferred system of the invention, the digital electronic camera conventionally has a shutter circuit for activating the shutter, to which shutter circuit electrical connection may suitably be made. Meanwhile, the overall system additionally includes a trigger circuit. This trigger circuit is within the enclosure and is electrically connected to the shutter circuit of the digital electronic camera. It serves to respond to some stimulus external to the enclosure so as to produce responsively thereto an electrical signal which, as and when supplied to the shutter circuit, will activate the shutter of the digital electronic camera.

The trigger circuit may be implemented in several different variants. A Hall-effect sensor responsive to a magnetic field can be used to produce a signal output, with an amplifier amplifying this signal output for application to the shutter circuit as the electrical signal responsively to which the shutter circuit will activate the shutter of the digital electronic camera. Triggering of the Hall-effect sensor may be realized by the simple expedient of manually moving a permanent magnet, external to the enclosure, into physical proximity to the Hall-effect sensor that is within the enclosure.

Alternatively, the trigger circuit may be based on a reed

switch, or sensor, that is also responsive to a magnetic field to gate an electrical signal responsively to which the shutter circuit will activate the shutter of the digital electronic camera.

Still further in the preferred system of the invention, the digital electronic camera has, as is again conventional, a rechargeable power source, normally a battery, for providing power to at least the digital electronic camera and also, in the case of the system of the invention, the converter. In this eventuality the overall system preferably further includes a charging circuit,

also within the enclosure, for converting some stimulus external to the enclosure to power suitable to recharge the rechargeable power source. The stimulus is preferably an oscillating, alternating current (a.c.), electromagnetic field. Accordingly, the preferred charging circuit includes (i) an inductive coil in which alternating current is induced by an oscillatory magnetic field external to the enclosure, (ii) a bridge rectifier rectifying the alternating current of the inductive coil to produce a direct current, and (iii) a regulating and charging circuit conditioning the direct current into power to charge the rechargeable power source.

The enclosure of the digital electronic camera and its associated auxiliary electronics is structurally simple and inexpensive, but functionally sophisticated. In one preferred

variant the camera and the converter (and any other incorporated features such as the trigger circuit and/or the charging circuit) are entirely potted in an optically clear dielectric material.

This optically clear dielectric potting material is preferably drawn from the group consisting essentially of plastic and any of hydrocarbon liquids, mineral oil, polyester resin and clear silicone rubber. The optically clear dielectric potting material is more preferably polycarbonate plastic and ethyl alcohol.

In a first variant of this potting, discussed further in section 3, below, the potting may extend into the interior volumes of the camera (and anything else, such as the inductive coil), so

that, ultimately, the enclosure contains only solid masses, and is devoid of any gas whatsoever.

In another, second, variant the (potted, or otherwise sealed) enclosure contains both solid and liquid masses, only, and there is still essentially no gas whatsoever within the enclosure nor within the camera that is within the enclosure. In this variant the liquid is an optically clear dielectric, and thus interferes with neither the optical functions of the camera nor the electrical functions of the camera and of the converter.

In yet another, third, variant the (potted, or otherwise sealed) enclosure may contain solid and/or liquid masses, but with a slight remaining volume between the elements of a compound lens, and/or between the lens and the (clear) camera case, in which is captured gas, normally air. This third variant camera may be quite easily constructed, typically requiring no alteration, even to the modest extent of de-focusing, of the optical system of the (digital electronic) camera. To such extent as the "gas pocket" is well protected, the camera may function at considerable pressures, and depths ranging to, typically, hundreds of feet. However, at the very greatest depths of the ocean, the gas pocket represents a compressible fluid, and its presence may undesirably physically distort the remaining structure of the encapsulated camera even if it does not lead to failure by rupture.

2. An Encapsulated Waterproof Digital Electronic Camera System

Therefore, in another of its aspects the present invention will be recognized to be embodied in a waterproof digital electronic camera where the optics and electronics of the camera are permanently within a solid mass of optically clear dielectric material, and where the camera contains essentially no gases whatsoever. By this construction the camera may suitably be immersed to great depth within the ocean without crushing.

In one variant of construction the digital electronic camera is potted inside and out to be within a solid block of optically

clear dielectric material, preferably plastic and more preferably polycarbonate plastic.

In another variant of construction the digital electronic camera is within an optically clear liquid dielectric material, the camera and its liquid being held within a liquid-tight exterior case that is itself optically clear in at least a region where an image is received through the case and into a lens of the camera. The preferred liquid is a liquid hydrocarbon, and is more preferably ethanol.

3. An Underwater Watch

As a further extension of the broad concepts of the present invention a completely sealed underwater watch can be made by encasing a digital watch, including its electronics and battery, inside a clear plastic slab. The settings of the watch can be changed using the hall-effect magnetic proximity switches described above. The watch battery can also be recharged as previously described for the waterproof digital electronic camera. Alternatively, the watch can simply be fitted with a single battery which will last for several years; the nominal life of the watch. (An optional photovoltaic array permits recharging.) The watch is economical yet operable at great depths and pressures since it is entirely embedded in plastic and there are no, or substantially no, air-spaces inside. These and other aspects and attributes of the present invention will become increasingly clear upon reference to the following drawings and accompanying specification.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring particularly to the drawings for the purpose of illustration only and not to limit the scope of the invention in any way, these illustrations follow:

Figure 1 is a cross-sectional top plan view of an air-filled first preferred embodiment of a waterproof digital electronic camera system according to the present invention, this first embodiment communicating digital information via an optical link.

5 Figure 2 is a combination electrical and mechanical detail schematic diagram of the preferred embodiment of a waterproof digital electronic camera system according to the present invention, previously seen in Figure 1, particularly showing a preferred shutter actuation interface.

10 Figure 3 is a combination electrical and mechanical schematic diagram of a preferred embodiment of a waterproof digital electronic camera system according to the present invention, previously seen in Figures 1 and 2, particularly showing a preferred optical-link data interface.

15 Figure 4 is a combination electrical and mechanical detail schematic diagram of the preferred embodiment of a waterproof digital electronic camera system according to the present invention, previously seen in Figures 1 through 3, particularly showing a preferred power switch interface.

20 Figure 5 is a combination electrical and mechanical detail schematic diagram of the preferred embodiment of a waterproof digital electronic camera system according to the present invention, previously seen in Figures 1 through 4, particularly showing a preferred recharging interface.

25 Figure 6 is a combination electrical and mechanical detail schematic diagram of the preferred embodiment of a waterproof digital electronic camera system according to the present invention, previously seen in Figures 1 through 5, particularly showing a first variant of the construction of a transformer within the preferred recharging interface previously seen in Figure 5.

30 Figure 7 is a combination electrical and mechanical detail schematic diagram of the preferred embodiment of a waterproof digital electronic camera system according to the present invention, previously seen in Figures 1 through 5, particularly

showing a second variant of the construction of the transformer of the preferred recharging interface previously seen in Figure 5.

Figure 8 is a cross-sectional top plan view, similar to Figure 1, of an air-filled variant preferred embodiment of a waterproof digital electronic camera system according to the present invention, this variant embodiment communicating digital information via a radio link.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Although specific embodiments of the invention will now be described with reference to the drawings, it should be understood that such embodiments are by way of example only and are merely illustrative of but a small number of the many possible specific embodiments to which the principles of the invention may be applied. Various changes and modifications obvious to one skilled in the art to which the invention pertains are deemed to be within the spirit, scope and contemplation of the invention as further defined in the appended claims.

The present invention is embodied in an underwater electronic digital camera which never needs to be opened except, perhaps, optionally, for replacement of a rechargeable battery. Even this apparent limitation to, and difficulty in, preserving the watertight integrity of the camera has a solution which will be described below.

1. The Housing

A cross-sectional top plan view of a first, air-filled, preferred embodiment of a waterproof digital electronic camera system 1 according to the present invention is shown in Figure 1. An entire digital electronic camera 11, including its optics 111, are contained within a waterproof case, or housing, 12. The digital camera 11 is preferably Kodak type DC 210: an electronic

digital zoom camera.

The housing 12 is preferably constructed of two plastic encasings 121 and 122, one fitting inside the other. The smaller inner encasing 121 is fitted over the camera 11 and its optics 111, forming a compartment 13. This compartment 13 is filled with air in a first variant embodiment of the camera system 1 and its housing 12, and with fluid or solid, polymerized, plastic in a second variant embodiment of the camera system 1 and its housing 12.

(1) Control wires 14 and (2) power wires 151, 152 connect the camera 11 through holes in the inner housing 121 respectively to (1) switches 161-163 and infrared (IR) PC interface link 17, (2) the power switch 181, and (iii) the battery 184 (itself connected to recharging circuit 183 and charging coil 182). Clear plastic resin is poured into the space interior to the outer housing 122 but exterior to the inner housing 121. This forms an economical yet hermetic housing capable of withstanding high underwater pressures at great depths.

A mass-produced version may be fabricated as a single casting of polycarbonate or LuciteSM plastic (Lucite is a trademark of Rohm & Haas, Inc.). The inner air compartment then consists of a thin-walled clear plastic box 121 embedded in a solid potting, or casting, which holds the optics 111 of the camera 11 aligned in the air compartment until the plastic cures.

2. The Switches

Switches 161-163, 181 in the form of reed proximity switches or Hall-effect devices are placed near the outer wall of the outer housing 122. To the outside of the housing 122, small rubber beads 191-194, each with an associated magnet 201-204 mounted on its outer surface, are placed near each proximity switch 161-163, 181. By depressing the rubber beads 191-194 with the fingers the associated magnets 201-204 are brought closer to the associated switch, activating the switches 161-163, 181. As may later best be

understood by reference to the partial schematics of Figure 3-5, this magnetic switching may alternatively be accomplished by Hall Effect semiconductor switches (at least in the locations of switches 161-163) -- which also results in a more sensitive switch design.

Hall-effect semiconductors also have the advantage of no moving parts without any requirement for such gas space -- required by the reed switches -- as may hinder use of the camera at great depth and pressure. However, for the gating of main power (see the pictorial partial schematic of Figure 4) a reed switch is superior since there will not be any leakage current. The main power switch 181 may be fashioned unlike the other switches 161-163 in that a latching mechanism must be provided. A simple sliding element as is diagrammatically illustrated in Figure 4, or, alternatively, a sideswipe lever (not shown), entirely fabricated from plastic can work to selectively emplace a magnet, normally embedded inside the manually slidable or otherwise movable part, into proximity with, or separation from, the switch 181.

However, for certain digital electronic cameras suitable for use in the present invention, such as the Kodak DC210, even the power switch is momentary in operation. Therefore all switches may suitably be implemented as Hall switches.

A preferred variant of any of the switches 161-163 (shown in Figure 1) is shown in detail in the combination electrical and mechanical schematic block diagram of Figure 2.

The first variant preferred shutter actuation interface includes a magnet 204 mounted on slide switch 1611 having a sliding lever 1613 and retained in the illustrated position by elastic bands, or plastic springs, 1612. Pressing with the fingers on the lever 1613 in the direction of vector A moves the side switch into the stop 1614, positioning magnet 204 proximate to Hall effect sensor 1615 and producing an electrical signal which, as amplified in amplifier 1616, suffices to trigger the shutter of the camera 11 (not shown in Figure 2; shown in Figure 1) electrically connected

to wire 1617. The Hall effect sensor 1615 is preferably Micronics type HAL 1145VA. The amplifier 1616 is preferably industry standard part number 7400.

The switch 181, which controls the application of power from the battery 184 to the camera 11, will be more particularly discussed in following section 4.

3. The Data Interface

The data interface of the waterproof digital electronic camera system of the present invention, and more preferably an infrared serial personal computer interface including the infrared (IR) PC interface link 17 shown in Figure 1, is illustrated in the combined schematic and diagram of Figure 3.

The preferred PC interface takes place through an infrared (IR) PC interface link 17 consisting of an RS-232C to TTL converter 171, an encoder-decoder 172 and an infrared IrDa compliant transceiver 173. The RS-232C to TTL converter 171, an industry standard part, receives serial data in the RS-232C interface format upon two 115,200 bit per second (bps) signal lines 174 from the digital electronic camera 11.

Then encoder-decoder 172 is preferably Hewlett-Packard type HSDL-7001. The infrared IrDa compliant transceiver is preferably Hewlett-Packard type USDL-0001. Together these components transmit the data received from the digital electronic camera 11 upon a digital optical, and more particularly an IrDA-compliant infrared, link.

These infrared pulses are detected by an IrDA adapter 3 to a personal computer (PC) 4. The preferred IrDA adapter 3 is the "Jeteye IrDA adapter" available from Extended Systems, Inc. This component converts the received infrared pulses back into an electrical RS-232C, other standard, interface format.

Accordingly, in the present invention electrical data signals from the digital electronic camera 11 are translated into optical pulses in the IR spectrum and passed through the transparent wall

of the camera's housing 12 to an integrated IR detector and signal converter, or IrDa Adapter 3, on the other side. The IR interface can easily handle the bandwidth required for data transmission in accordance with the RS-232C interface standard, even at high baud rates. The entire process is opaque to both (i) the digital electronic camera 11 and the firmware operating therein, and to (ii) the PC 4 and the software operating therein.

4. The Power Switch

The preferred power actuation interface shown in Figure 4 again uses a magnet 204, now mounted on toggle switch 1811 having a swing arm 1812 retained in the illustrated position by a latch 1813. Moving, under force of the fingers, the magnet 204 proximate to the Reed relay switch 181 closes this reed switch 1814, gating power through the path thereby established from the battery 184 to the camera 11 (both shown in Figure 1).

4. The Recharging Interface

A charging coil 182, preferably with a ferrite core (as will be more particularly illustrated in Figures 6 and 7) is located inside the plastic outer housing 122. This charging coil connects to a charging circuit 183 and through this circuit to a battery 184.

When the battery is to be recharged, another coil carrying an alternating current (not shown in Figure 1, shown in Figures 6 and 7) is placed outside the other housing 121 proximately to the charging coil 182, and is aligned to induce current in this internal charging coil 182. The outer coil acts as the primary winding of a transformer while the inner, charging, coil 182 acts as the secondary. The alternating current inductively induced in the inner (secondary) charging coil 182 is then rectified, filtered and regulated in the charging circuit 183 and applied as a d.c. current to charge the battery 184. In this way the battery 184 can be charged without any need for opening the housing 122, or even

for having any wires to penetrate the housing 122. The battery 184 is charged and recharged entirely while it is continuously within the plastic housing 122.

5 The battery 184 may be located behind a frangible barrier, or membrane (not shown in isolation, but within the surface of the case 12). This barrier may be broken, pried open or the like, and the battery replaced. Then the barrier, or a substitute replacement barrier, is replaced, normally by use of adhesive, so as to again render the battery 184 and the interior of the case 12 again gas-tight.

10 A detail combination electrical and mechanical schematic block diagram of the preferred embodiment of the recharging circuitry for the waterproof digital electronic camera system according to the present invention, previously seen in Figures 1 through 4, is shown in Figure 5. An external source of a.c. power 15 is inductively coupled through transformer 18; the secondary winding of which is the charging coil 182 located inside the housing 12 (shown in Figure 1). The a.c. current induced in the charging coil 182 (a transformer winding) is communicated to rectifier 1831, normally a simple diode bridge, and filtered as a d.c. voltage in capacitor 1832. The d.c. voltage and current is conditioned in battery charging circuit 1835 and applied to charge battery 181. Power from the battery 181 may optionally be regulated in voltage regulator 1824 before application to camera 18 (shown in Figure 1).

20 These same components of Figure 5, now in conjunction with a first, and a second, variant embodiments of the transformer 18, are respectively illustrated in Figures 6 and 7. The physical design of the transformer 18a of Figure 6 realizes good inductive coupling between the primary and secondary coils of the transformer because the primary coil is (in terms of the flow of magnetic flux) located across the secondary coil. The transformer 18 configuration requires that the charger for the camera -- which is, of course, normally used only when the camera is not in use for imaging --

have a greater thickness than does the camera, which some users may find objectionable. Although the primary coil is still, in terms of the flow of magnetic flux, located across the secondary coil in the variant embodiment of Figure 7, the primary and secondary windings of the transformer 18 are of equal thickness, and the charger for the camera 11 may be as thin as is the camera itself.

5. A Solidly Encapsulated Embodiment

An alternative second embodiment of the hermetically sealed digital electronic camera in accordance with the present invention is essentially the same as the first embodiment with one important difference: the entire camera including both the camera electronic and optics are cast into clear casing resin or other clear plastic.

The optics are normally constrained to be immovable, and thus focus free. These focus free optics may be preset, or, in extreme cases, custom designed by aid of standard ray-tracing lens design programs that accord consideration to the indices of refraction of all media in the optical path, so as to correctly accommodate the index of refraction of the clear plastic medium which is, of course, different than that of air.

This solidly encapsulated design offers the advantage of easy manufacture while permitting camera operation to virtually any depth under water because, with virtually no airspace within the camera, there is no pressure differential between the outside and the inside of the camera. Like the more rudimentary hermetic sealing of the camera with some gas still inside, the second embodiment is enabled by the fact that the camera never needs to be opened during all phases of operation.

5.1 A Fluid-Filled Housing Variation on the Second Embodiment

A variation on the second embodiment of the invention employs a housing that is fluid-filled, or that is at least in part fluid filled. The preferred fluids are clear dielectrics. Both common mineral oil and synthetic gel suffice. However, if the fluid is

present in the optical path, fluids with high optical transmissivity are preferred. These fluids are associated with fluid-filled optical light pipes, and may readily be located in, inter alia, the patent literature on this precise subject.

5 Note that certain fluids transmit better in certain regions of the optical spectrum. Clearly any fluid in the optical path of the digital camera should be chosen in consideration of the frequency of the images desired to be registered by the camera. For example, the electronic sensor array plane of the camera need not be a Charge Coupled Device (CCD) targeted on visible light, but may instead be an active pixel array sensitive, in the manner of the common use of these arrays in telescopes, to infrared light. Clearly if the digital electronic camera is to capture images in infrared light, any liquid (or solid) in the optical path would be highly transparent to light of this frequency.

10 The housing is closed around the fluid or gel, and experiences zero pressure differential. Yet the camera electronics are protected. This variant embodiment has the advantage that housing could be opened and the camera electronics removed for servicing. Also, in the event that the camera optics must move, such as to focus, the fluid or gel can accommodate this.

6. Optional Replacement of the Rechargeable Battery

Any replacement of the rechargeable battery which may at some point become necessary may, in accordance with the present invention, optionally be made possible by having a battery compartment located near the outside of the housing. The battery is installed in a suitable battery holder and then this sub-compartment is filled with, preferably, a soft-casting plastic (a silicone seal or similar) which provides a hermetic seal around the battery and all wires and contacts. When the battery is to be replaced, the soft silicone is cut away with a small knife and the battery replaced. Upon replacement of the battery, the battery compartment is then refilled -- normally as tightly as is possible

-- and is, at a minimum, capped over with soft silicone rubber.

7. Gas-filled, and Solid- or Liquid-Filled, Embodiments of the Underwater Electronic Digital Camera

5 In one embodiment of an underwater camera in accordance with the present invention, the optics of the camera, or the entire camera, is encapsulated within an air compartment within the camera housing. This design has the advantage that the camera optics do not need to be redesigned for atmospherically-based usage, but the disadvantage is that there will be a pressure differential between the outside water pressure and lower gas (air) pressure inside the compartment, which will, at some depth, become a limiting factor in the design. However, even this design is operable at depths of five hundred feet (500') with the use of only inexpensive plastic materials because the housing is made from a single piece of cast plastic with no openings or seals. There is thus no problem with leakage which exists with conventional O-ring seal designs for underwater cameras.

10 In another embodiment of an underwater camera in accordance with the present invention, the entire camera is embedded in an optically clear plastic potting material (such as polycarbonate), including, most notably, the (focus-free) optics of the camera. When the camera is delivered into use this potting plastic is solid, and permanent. In a variant of this embodiment the camera, and more normally the camera and the entire interior of the watertight case within which it and any accompanying auxiliary electronics are housed, is filled with a clear liquid, normally ethanol.

20 This embodiment, and both these variants, have the disadvantage that the camera optics have to be designed for the different index of refraction of the clear plastic potting material, or the liquid, as opposed to air. Also, if the potting plastic solidifies hard (which is normal), then there cannot be any moving parts, making that the camera optics have to be focus-free,

and unmoving. When the camera enclosure is filled with a clear dielectric fluid then mechanical focusing of the camera optics is still permitted. However, care has to be taken in that (1) the immersion fluid is not normally a satisfactory lubricant, (2) material from the camera may become dissolved and/or dispersed in the fluid, clouding its clarity and interfering with photography, and/or (3), depending upon the differential compressibility of the immersion fluid versus water, the fluid may still slightly compress and the camera body distort at very great depths, normally a mile or more.

The advantage of the second embodiment is that an inexpensively housed and adapted conventional digital electronic camera can be made to be operable at essentially any depth. This is because a total absence of air inside the camera housing precludes that any pressure differential should arise between the outside and the inside of the camera. The fact that this can be achieved with an inexpensive design makes this embodiment of an underwater camera in accordance with the present invention particularly novel and attractive.

8. A Variant Embodiment Underwater Electronic Digital Camera Communicating Digital Data Via Radio

A cross-sectional top plan view, similar to Figure 7, of this variant preferred embodiment of a waterproof digital electronic camera 1a according to the present invention is shown in Figure 8. This variant embodiment system 1a communicates digital information via a radio link.

A digital camera 11 is again preferably Kodak type DC 210. The RS-232(C) interface 174 to this camera now connects to, and through, 2.4 GHz spread-spectrum transceiver modules 373 to an external personal computer, or PC, 4. The preferred 2.4 GHz spread-spectrum transceiver modules 373 are type DG24RFA from the extensive DGRO/DRG24 families of board level radio frequency transceiver modules available from FreeWave Technologies, Inc.

Radio data transmission may transpire at speeds up to 115.2 kbaud.

9. Recapitulation, and Extension, of the Concepts of the Present Invention

There are at least four primary features to the waterproof digital electronic camera system of the present invention. First, the method of designing the housing within the housing accords for an air space which contains the camera or at least the camera optics. Second, the design of the electronic switches permits operator control of the camera while it is submerged nonetheless that these switches require no holes through the housing whatsoever, thus preserving the water-tight integrity of the housing. Third, the method of recharging the battery of the camera does not require opening of the housing, nor the presence of any holes in the housing. Fourth, the infrared optical interface to a communicating PC requires neither any opening of the housing, nor any openings in the housing.

These concepts of the present invention described herein this specification are of broad applicability. Namely, the concepts of (i) potting the auxiliary electronics and the digital electronic camera together to provide an inexpensive watertight housing, (ii) magnetically activating essential switches of the both the momentary and dual-state types, (iii) communicating data to a computer upon an infrared optical data interface through a clear housing, (iv) breaking or otherwise disrupting a frangible or removable seal to optionally replace a battery, (v) filling the housing with a dielectric fluid which may either remain liquid or solidify, and (vi) still other concepts, can all be applied to diverse underwater devices other than digital electronic cameras.

For example, an underwater light could be made using these design features. Also, when an all-digital video camera with no moving parts becomes a reality, this video camera can be housed the same way, and the pictures retrieved to a computer interface, in the identical manner as the digital electronic still camera of the

present invention.

Accordingly, the concepts of the present invention should be understood to be broadly applicable to digital electronic equipments deployed in underwater, marine, adverse weather and contaminated environments of various natures.

By way of a further particular example, and underwater digital watch can greatly benefit by several of the concepts of the present invention. The watch may employ each and any of the (i) encapsulating housing, (ii) inductively coupled battery recharging, and/or (ii) magnetically actuated switching concepts of the present invention. The may be, in particular, completely potted and sealed in strong plastic for underwater operation.

In accordance with the preceding explanation, variations and adaptations of the hermetically sealed digital electronic camera system in accordance with the present invention will suggest themselves to a practitioner of the electronics and optics packaging arts. For example, data could be communicated to and from the camera over and inductive electrical link in the manner of U.S. Patent 5,455,466. A design need not embrace each and every disparate aspect of the present invention to be within the scope of the invention, as defined by the attached claims. At least when the battery is not replaced, the underwater camera of the present invention is the first, to the inventor's knowledge, to house a function camera in a case that is totally without such holes or orifices as have commonly previously fitted mechanisms for transmitting mechanical forces, or wires for communicating electrical power and/or signals. Even if the battery replacement option is employed, the hermetically sealed digital electronic camera system of the present invention can fairly be described as "seal-less" in that its case, while certainly "sealed", has no "seals" in the sense that some crack or orifice through which water and/or contamination might otherwise enter has to be "patched over" with a "seal" that otherwise permits the movement of something -- mechanical force or electricity or whatever -- through the region

of the seal.

In accordance with these and other possible variations and adaptations of the present invention, the scope of the invention should be determined in accordance with the following claims, only, and not solely in accordance with that embodiment within which the invention has been taught.

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